PATENT SPECIFICATION 897,575

DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Methods of and Apparatus for Preventing Surging in Single-Stage or Multi-Stage Radial Flow Compressors.

We, SULZER FRERES, SOCIETE ANONYME, a Company organised under the Laws of Switzerland of Winterthur, Switzerland, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to methods of operating single-stage or multi-stage centrifugal compressors and to compressors suitable for operating in accordance with the method.

In centrifugal compressors, on the reduction of the delivery below the surging or pumping limit the flow of the working medium through the machine may become discontinuous. Periodic pressure fluctuations then occur, accompanied perhaps by a periodic reversal of flow.

A known remedy consists in blowing off working medium from the delivery pipe by means of a blow-off valve, through which at least sufficient working medium to raise the rate of flow to the surging limit is blown off. The advantages of the simple construction of such an arrangement are offset by the disadvantage of an energy loss which increases with the amount of working medium discharged, because the work done in compressing the working medium blown off is wasted.

Instead of blowing off working medium it has been proposed to return a quantity of working medium to the suction side of the compressor, sometimes through a recuperation turbine where energy may be extracted. The direct return of working medium affords no improvement as regards wasted energy over blowing off to atmosphere. The arrangement with a recuperation turbine is expensive and gives no-load losses in the stable working region, and these impair the overall efficiency.

The present invention enables surging to be reduced or avoided in a simple manner and without it being necessary to accept an excessive deterioration of the efficiency.

According to one aspect of the present invention a method of operating a single-stage or multi-stage centrifugal compressor comprises, on reduction of the volumetric delivery to near the surging limit for operation without intermediate discharge of working medium, discharging a part of the working medium from the passages formed by the moving blades of the rotor (or at least one of the rotors in a multi-stage compressor) at a point intermediate between the inlet and outlet ends of this rotor to a region at a pressure below the delivery pressure of the rotor, thereby reducing the volumetric delivery without surging to below what would be the surging limit for operation without intermediate discharge.

The intermediate point of discharge is preferably so selected that the pressure of the working medium in the moving blade passages at the point of intermediate discharge is just sufficient to overcome the resistance to flow of the working medium in passing to a point of lower pressure. This point will normally be in the upstream half of the passages formed by the moving blades.

By employing the method of the invention, the delivery of the rotor of the stage in question can be reduced to a very small amount without surging occurring. Since part of the working medium is discharged before reaching the ends of the blade passages formed by the moving blades, the total energy to be applied for acceleration of the

working medium in the blade passages is considerably reduced. Moreover in spite of the intermediate discharge of part of the working medium from the first half of the blade passages the rotor inlet is subjected to shock-free flow, since the relative speed of entry, which assumes a magnitude and direction according to the intake volume at any time, is not of course influenced by the intermediate discharge of working medium which follows after the entry to the rotor. Thus surging will be avoided since surging is caused by separation phenomena resulting from shock.

According to a second aspect of the present invention a centrifugal compressor suitable for operation by the method of the invention comprises an open rotor having blades with blade passages between them, a non-rotating wall bounding one side of the passage, the wall containing an intermediate outlet in the form of an annular slit between the suction and delivery ends of the passages and which can be brought into communication with a region of lower pressure than that normally existing at the intermediate outlet of the rotor, and means for varying the width of the slit.

In the case of a multi-stage compressor having a first-stage with an open rotor and the subsequent stage or stages with shrouded rotors the intermediate outlet is provided in the first stage.

The invention may be performed in various ways, and one form of carrying out the method with a known form of compressor, and a novel compressor suitable for performing the method, will now be described by way of example with reference to the accompanying drawings, in which:—

Figure 1 is a longitudinal section through part of the known single-stage centrifugal compressor having an open rotor;

Figure 2 is a graph showing the relation between pressure and volumetric delivery, and between efficiency and volumetric delivery for operation with and without the intermediate discharge of part of the working medium according to the invention; and

Figure 3 is a longitudinal section of two stages of a novel multi-stage centrifugal compressor.

The compressor shown in Figure 1 has an open rotor 2 which is fastened on a shaft 1 and the blades 3 of which form blade passages 4. The working medium flows substantially axially into the suction end of the rotor, and is delivered in a radial direction into a fixed diffuser 5. For the sake of simplicity, only the parts necessary for an understanding of the present invention are illustrated.

The rotor 2 is surrounded by a stationary housing 6 and 7 of which the wall 8 bounding the open side of the blade passages 4 has an annular slit 9 which opens into the blade passages at a point where the working medium has flowed through only a third of the length of the passages. The annular slit 9 leads into an annular chamber 10 to which is connected a pipe 11 fitted with a flow regulating valve 12. For operating the compressor by the method of the invention the pipe 11 communicates with a region of lower pressure, for example with the atmosphere.

To prevent surging at reduced delivery, the flow regulating member 12 is opened at least to such an extent that the operating point is situated in the stable working region on the new characteristic curve as shown in Figure 2.

The graphs in Figure 2 show the relation between delivery pressure P plotted on the y—axis and volumetric delivery V plotted on the x—axis for different operating states at constant speed of rotation. The curve *a* is the characteristic curve for operation without intermediate discharge of working medium through the slit 9. Point A indicates the surging limit; a reduction in flow below V_A which corresponds to the surging limit is impossible without surging. The curve *b* is the new characteristic curve for operation with the intermediate discharge of working medium from the blade passages through the slit 9 as proposed by the invention. The surging limit in this case is at a delivery V_B corresponding to the point B; the delivery can thus be reduced considerably without surging occurring. The curve *b* corresponds approximately to a characteristic curve with the intermediate discharge of working medium of, for example, 70% of the total quantity of working medium entering the rotor. Between the curves *a* and *b* are corresponding characteristic curves (not shown) for operation with intermediate discharge of a smaller quantity of working medium than is the case for operation according to the characteristic curve *b*.

The curves a^1 and b^1 are the efficiency curves for operating states lying on the curves *a* and *b* respectively, efficiency z being plotted on the y—axis. Without the intermediate discharge of any working medium there is a usable working region *c* between the deliveries V_A and V_{A_1}. As a result of the described adjustable intermediate discharge of working medium the useful working region is increased to the delivery V_B, so that the entire region *d* between V_{A_1} and V_B is available.

Figure 3 shows part of a multi-stage compressor in which in each of the first two stages shown an intermediate outlet can be produced for the intermediate discharge of working medium from the moving blade passages. The first stage rotor has blade passages 22 which are bounded partly by

a stationary part 29 of the compressor housing and partly by a wall 23 of a movable ring 24. The ring 24 is mounted to be axially slidable in the compressor housing and can be adjusted by means of a rod 25, a crank arm 26 and a control rod 27. By turning the control rod 27 an annular slit 28 is formed between the ring 24 and the fixed part 29 of the housing. The second stage of the compressor is constructed in the same way and the corresponding parts are denoted by like reference numerals provided with an apostrophe.

The rods 27 and 27' may be suitably coupled together so that an increase or decrease in the size of the slit 28 at the same time produces a corresponding variation in the slit 28'. On the other hand the slits may be independently adjustable. When the gap 28 or 28' is open a quantity of working medium flows out of the blade passages into an annular chamber 30 or 30' from which it passes through a pipe 31 or 31' to the atmosphere. The operation is similar to that of the compressor shown in Figure 1.

In multi-stage compressors all or only one or some of the stages may be provided with intermediate outlets for the discharge of working medium from the blade passages. A particularly advantageous embodiment of a multi-stage compressor is one in which the first stage has an open rotor and the other stages have shrouded rotors, means for the intermediate discharge of working medium from the blade passages being provided in the first stage.

It generally happens that when a multi-stage compressor is operating with a smaller total pressure ratio than that for which it is designed, the first stage tends towards surging on the reduction of the delivery. Conversely, surging generally first occurs in the last stage when the total pressure ratio is greater than that for which the machine is designed. In some cases, therefore, it may be advantageous to provide only the last stage of a multi-stage compressor with means for intermediate discharge of working medium from the blade passages.

It will be understood that the method of the invention is not limited to the embodiments described. Thus it would be possible in compressors with shrouded rotors, to discharge working medium from the blade passages in one or more stages, for example through bores in the shroud plates of the rotors. Moreover, it would be possible to return the working medium discharged through the intermediate outlet to the suction side of the compressor or of a compression stage.

WHAT WE CLAIM IS:—

1. A method of operating a single-stage or multi-stage centrifugal compressor which comprises, on reduction of the volumetric delivery to near the surging limit for operation without intermediate discharge of working medium, discharging a part of the working medium from the passages formed by the moving blades of the rotor (or at least one of the rotors in a multi-stage compressor) at a point intermediate between the inlet and outlet ends of this rotor to a region at a pressure below the delivery pressure of the rotor, thereby reducing the volumetric delivery without surging to below what would be the surging limit for operation without intermediate discharge.

2. A method as claimed in Claim 1 in which the point of discharge of the part of the working medium is in the upstream half of the passages formed by the moving blades.

3. A centrifugal compressor suitable for operation by the method claimed in Claim 1 and comprising an open rotor having blades with blade passages between them, a non-rotating wall bounding one side of the passages, the wall containing an intermediate outlet in the form of an annular slit in the wall between the suction and delivery ends of the passages and which can be brought into communication with a region of lower pressure than that normally existing at the outlet of the rotor, and means for varying the width of the slit.

4. A compressor as claimed in Claim 3 having more than one stage, the first stage having an open rotor and the subsequent stage or stages having shrouded rotors, and in which the intermediate outlet is provided in the first stage.

5. A method of operating a centrifugal compressor as claimed in Claim 1 and substantially as described with reference to Figures 1 and 2 of the accompanying drawings.

6. A centrifugal compressor substantially as described herein with reference to Figure 3 of the accompanying drawings.

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Chartered Patent Agents.

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Fig. 1

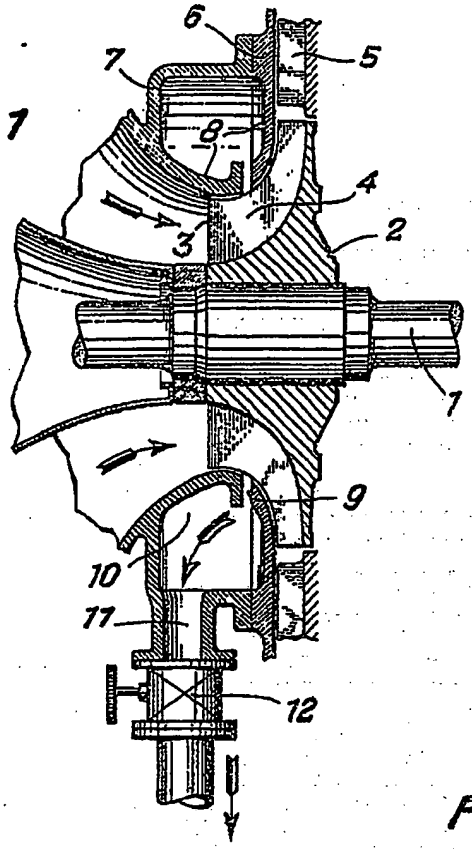
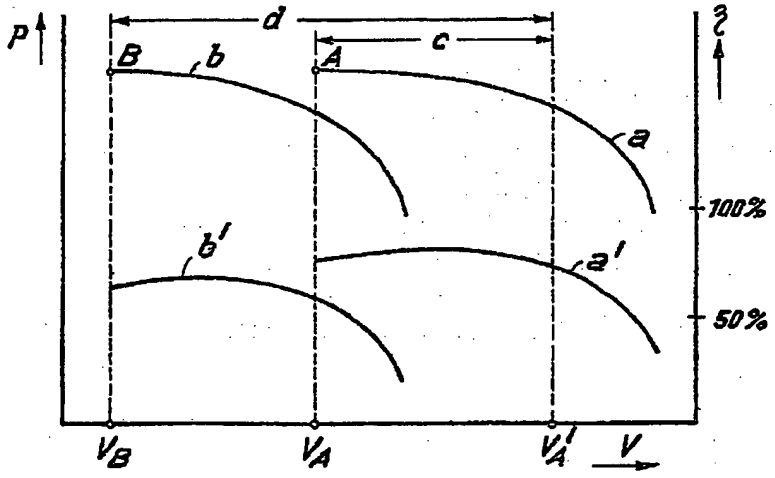


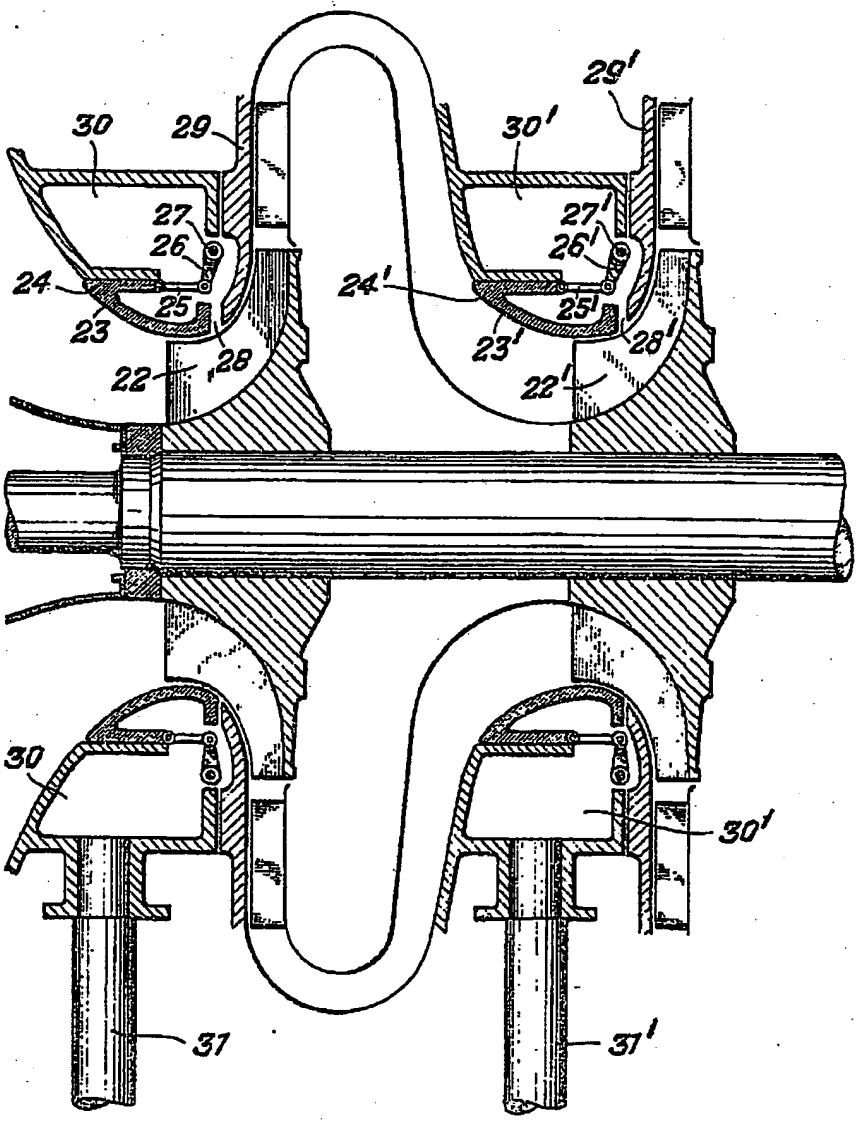
Fig. 2



897,575 COMPLETE SPECIFICATION
2 SHEETS

This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2

Fig. 3



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SHEETS 1 & 2

Fig. 1

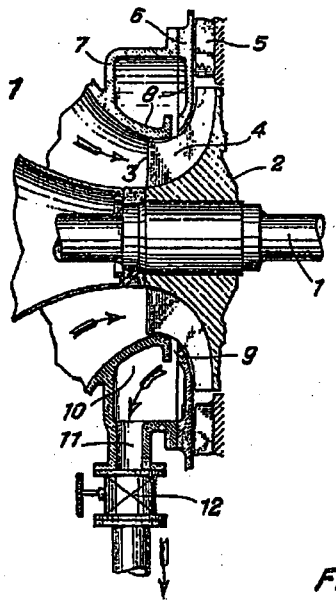

Fig. 2

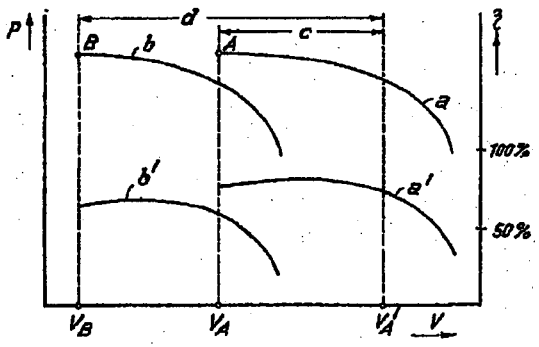

Fig. 3